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Emerging technologies for real-time and integrated agriculture decisions

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ABSTRACT

The papers in this special issue arise from the premise that precision agriculture information increases in value when data collection, data processing, and management actions are integrated. It seems evident that precision agriculture adoption has been hindered, in part, due to the lack of products that bring together engineering and agronomics. Additionally, the idea has been forwarded in recent years suggesting that precision agricultural systems should be developed to achieve conservation and other environmental benefits. In the end, users of precision agriculture systems want to know that the best science and technology are employed, but that the information-gathering and decision-making process does not hinder their day-to-day operations of producing the crop. The papers in this special issue were presented at a symposium held at the annual meetings of the American Society of Agronomy, Soil Science Society of America, and Crop Science Society of America in 2005. They highlight examples of spatial information collection and processing to accomplish real- or near real-time management operations.

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1. Introduction

Advances in sensors, computers, and communication devices continue to change the ways of agriculture. Information-driven management has been fundamental to modern agriculture for many decades, but until recently the decisions were simple and the scale was broad. However, over the past 20 years as the capacity to collect both different types and greater amounts of temporal and spatial information has mushroomed, so has the need to accelerate the processing of information into reliable decisions. Indeed, as farmers' and researchers' hard drives have filled up with images, maps, and data-filled spreadsheets, they have become painfully aware of the obvious:

> "We are drowning in information and starving for knowledge." Rutherford D. Roger

With information-driven agricultural systems such as precision agriculture, basic principles of resource management cannot be ignored. Time and capital resources spent to collect intensive information from production fields, and then process that information into practical decisions, need to be offset by some type of improvement. If this is not realized, negative feed-back to the investor (the producer) will result in a retreat to former ways. The paramount test of improvement in an open market-based economy is profitability, since financial matters have the greatest effect on a crop producer's decision of whether to adopt practices long-term

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or not (Griffin and Lowenberg-DeBoer, 2005; Kitchen et al., 2002; Lamb et al., 2008). Additionally, the idea has been forwarded in recent years that a precision agricultural system should include conservation measures that provide environmental benefits (Berry et al., 2003; Kitchen et al., 2005). In precision agriculture, the 1990s fascination with harvesting data has been tempered in more recent years by the realization that better decisions were often not being made. Many have actually found with more and more information collected a diminished motivation to do something with it. In cases, the ability to meaningfully apply the information gathered in order to reap benefit(s) just has not materialized (Bullock et al., 1998; Griffin and Lowenberg-DeBoer, 2005). From such, an obvious but blatantly truthful perspective arose.

> "It is not good to know more unless we do more with what we know." R.K. Bergethon

The following premise has thus emerged: precision agriculture information increases in value when data collection, data processing, and management actions are integrated. Even the case that precision agriculture research and development will only succeed as an integration of multiple disciplines has been forwarded (Bullock et al., 2007). End users want to know the science and technology are employed, but not necessarily the details of how or why that information is needed for an action. This phenomenon is typical of all consumers of new applications of science or technology. For precision agriculture, seamless and automated applications is captured in what Griffin and Lowenberg-DeBoer (2005) described as "embodied knowledge", that is information needs to be purchased in the form of an input (e.g., hybrid corn). Since modern farming enterprises are already complicated and time-demanding, producers seeking improvements want science and technology delivered, but without increased complexity. Convenience is a major driver.

Given these observations, what are the characteristics of viable precision agriculture systems of the future? Four points seem certain. When at all possible, the information-to-action decision process needs to be: (1) in situ sensor-based; (2) automated for real-time (or near real-time) computer processing into decisions (the task of "post processing" is quickly becoming antiquated); (3) packaged so that sensing and processing of information are a part of the equipment used to accomplish the required management action; and (4) transparent to the operator/manager for decision confirmation. This last point is important for two reasons. First, producers want to maintain control, described as the "human touch" (Griffin and Lowenberg-DeBoer, 2005), since management is still viewed as much as an *art* as it is an application of *science*. Second, since technology is not fail-proof, the operator needs to have over-ride control based upon his own experience of what is right.

To give attention to these four points and provide examples where sensor-based, automated, real-time decisions were employed, a special symposium was organized at the 2005 Joint Annual Meetings of the American Society of Agronomy, Soil Science Society of America, and Crop Science Society of America. The title of that symposium and the basis of this special issue was *Emerging Technologies for Real-time and Integrated Agriculture Decisions*. These papers represent a diverse set of examples of information types and decisions made; they are a small subset of the possibilities that could have been given. The examples here range from investigative to commercialized products. In some cases, the full process demonstrating data, collection, decision, and action is illustrated. In other cases, this full process may still be a few years away. Yet with all these cases, the merging of engineering and agronomic science is evident and defining of future precision agriculture. Here I briefly describe each paper and point out common elements in support of real-time and integrated agriculture decisions.

2. Special issue organization

Often, technology advances outpace the readiness of potential users. This certainly has been the case with many of the advances in precision agriculture. In the first paper, Lamb et al. (2008) outlines adoption paradigms and, from examples in Australia, puts them in the context of crop production systems. Claims of increased profitability from measuring, mapping, and site-specific management have in many instances fallen short, conditioning farmers to be more skeptical of precision agriculture. This paper explores differences in motivations between developers and marketers of precision agriculture and the users. In hind-sight, clear gaps between the two are obvious. The authors go on to suggest some meaningful ways that the gaps can be closed. For example, establishing industry-wide protocols early on for new products and services lays a foundation that helps reduce risk by adopters. The paper articulates well the need to reflect and learn from what has happened in precision agriculture in order to better define and apply the science and technology of precision agriculture in the future.

Managing soil for agricultural purposes is fundamentally a challenge. The difficulty starts with the inherent heterogeneity of soil constituents (mineral, organic mater, solution, gases) relative to chemical and physical properties important to plant growth. Yet to best manage a crop one first needs to manage the soil, and requisite for doing that is a careful characterization of important soil properties. The process of soil sampling, transporting out of the field then laboratory analysis, and interpretive mapping is arduous and expensive. Ultimately (and if at all possible), these steps need to be accomplished in situ. The next two papers provide examples where soil characterization sensors are being developed and evaluated with "in situ" as the goal. Christy (2008) describes the use of an on-the-go near infrared reflectance spectroscopy sensor and a calibration/validation process for measuring a number of different soil attributes, such as organic matter, pH, and phosphorus. As an example, the sensor system could predict about 66% of the variation in soil organic matter within fields. While calibration may be necessary for each field or group of fields in close proximity, a major advantage of on-the-go spectral data is that it can provide full coverage of field variation and then be used to target sampling for an optimal calibration. A second paper addresses the issue of soil compaction. Remediation of this problem on crop production fields starts with understanding the severity, the areal extent and depth of compaction. A side-by-side field assessment of two on-the-go soil compaction sensor systems capable of sensing compaction at various soil depths is presented by Sudduth et al. (2008). Here they show these sensors gave results comparable to traditional cone penetrometer measurements. With increasing energy costs, interest is growing for integrating these kinds of sensors on tillage or other equipment so that compaction can remedied in a cost-effective one-pass procedure.

While *climate* defines crop suitability for a given location, it is the day-to-day (or even the hour-to-hour) *weather* information that producers often require for in-season decisions. The next paper by Pierce and Elliott (2008) describes how critical decisions in the orchard and vineyards of Washington (U.S.) are being improved through use of weather data obtained through wireless sensor networks. In this application efficiency can be greatly increased and costs reduced through automation. Examples are also given of how these same wireless networks are being used to gather other types of time-sensitive information such as soil moisture for irrigation scheduling, grape load monitoring, and real-time manure application monitoring (a Wisconsin example). The paper further describes how decisions are more streamlined and site-specific when using on-farm wireless network systems for monitoring air temperature during critical frost periods.

Many cropped fields worldwide display a high degree of within-field variation in plant available water capacity. For fields managed with irrigation, being able to vary the amount and timing of watering would be ideal. In a second paper on wireless sensor systems, Vellidis et al. (2008) discuss linking soil moisture sensors to Radio Frequency ID (RFID) tags. Data transmitted to a local receiver monitors variable water needs of crops within fields. Interest in this technology is driven by a motivation to improve crop production and decrease energy costs. Systems as described in this paper are being used on a limited basis for cotton and peanut fields in the southeast USA to schedule and control variable-rate irrigation applications.

An example of a precision agriculture technology that accomplishes collection, decision, and action in one-step is the use of ground-based active-light reflectance measurements for conducting variable-rate nitrogen fertilizer applications. In a paper by Shanahan et al. (2008) the rationale for using plant-based sensing is described in detail. Without strategies to address site-specific nitrogen need that enable synchronization of fertilization with crop nitrogen uptake, nitrogen use efficiency worldwide will remain low (~30%). While there has been some limited adoption of these sensors on crop production fields, additional on-going studies worldwide are needed to refine the algorithms used for generating fertilizer recommendations. The paper suggests improved recommendations as these sensor measurements are integrated with other soil and crop information processed into management zones.

A final paper comprehensively reviews the technologies and strategies for controlling crop weeds using automated robotic control (Slaughter et al., 2008). Described are four core technologies inherent in this management objective, including guidance, detection and identification, precision in-row weed control, and mapping. Use of RTK DGPS using local base stations has been particularly successful for automated guidance of cultivation and herbicide spraying equipment. Adoption is quickly becoming widespread in some countries. The authors show how the process of weed detection and species identification under highly variable field conditions (e.g., soil color, wind, plant color and shape, water stress) remains the greatest challenge for automated weed control.

3. Summary

Use of computers and sensors for real-time decisions in cropping systems is increasing rapidly. Yet, the value of technology can be best realized when integrated with agronomic knowledge, resulting in a seamless process of assessment, interpretation, and targeted operation. Success stories shared can help promote this new way of agricultural management. Examples shown in this special issue highlight just a few of the possibilities, and stimulate thoughts for other opportunities.

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